LA-UR-02-5703

Abstract

Multi-purpose Acoustic Sensor

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Acoustic sensing based on frequency sweep technique has been developed to monitor the wall thickness, wall material sound speed, pipeline internal cross-section variation, and the presence of contamination (e.g., chemical or biological agents related to terrorist activities) in the gas in the pipeline. These sensing techniques are adapted from the instruments developed for the Department of Defense. Preliminary results of the laboratory experiments will be presented and the theory of the frequency sweep technique will be described. The primary objective of this effort is to develop a multi-purpose sensor system that can monitor multiple characteristics of natural gas pipeline integrity simultaneously. The complete suite of monitoring includes the measurement of velocity/flow of gas, presence of gas leak, and structural defects.

Multi-purpose Acoustic Sensor

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Natural Gas Infrastructure Reliability Industry Forums
Morgantown, WV
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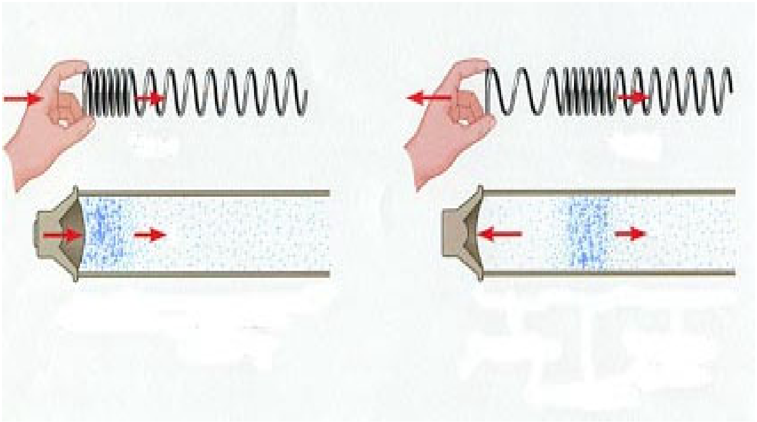
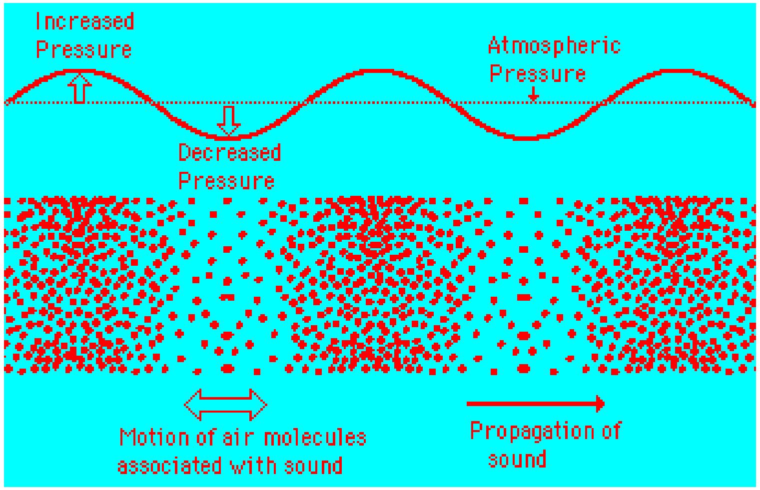
Multi-purpose Sensor Capabilities

- Determine the variation in the internal cross-section of the pipe
- Measure wall-thickness all around
- Detect gas contamination in pipeline
- Measure velocity/flow of gas
- Detect presence of gas leak
- Determine structural defects in the pipe

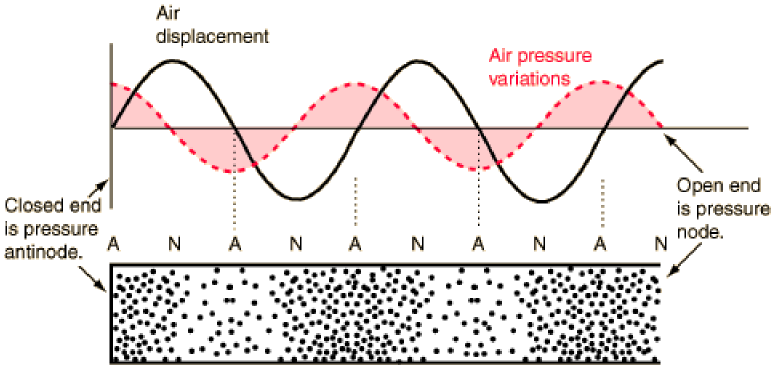
1-3 represent approximately 3 month's worth of effort
Work started in June 2002.

Sound is a Pressure Wave





Standing Wave



Only at certain frequencies

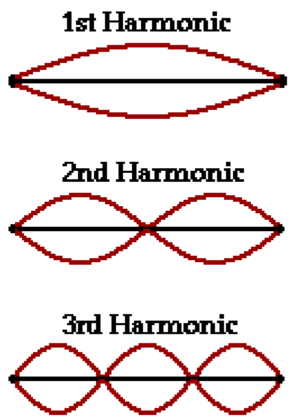
Determination of Fluid (Liquid, Gas) Physical Properties using Standing Waves

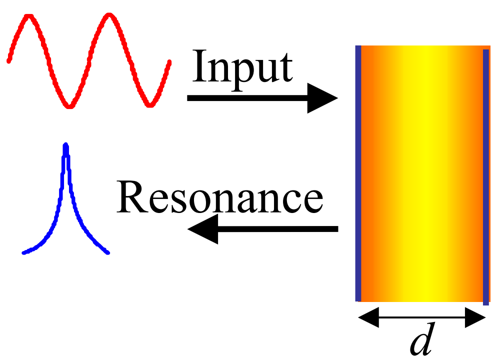
Resonance occurs when:

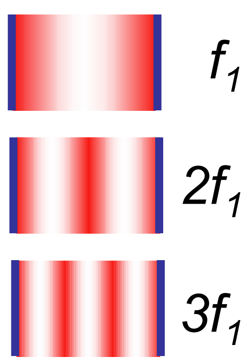
$$d = n\frac{\lambda}{2}$$

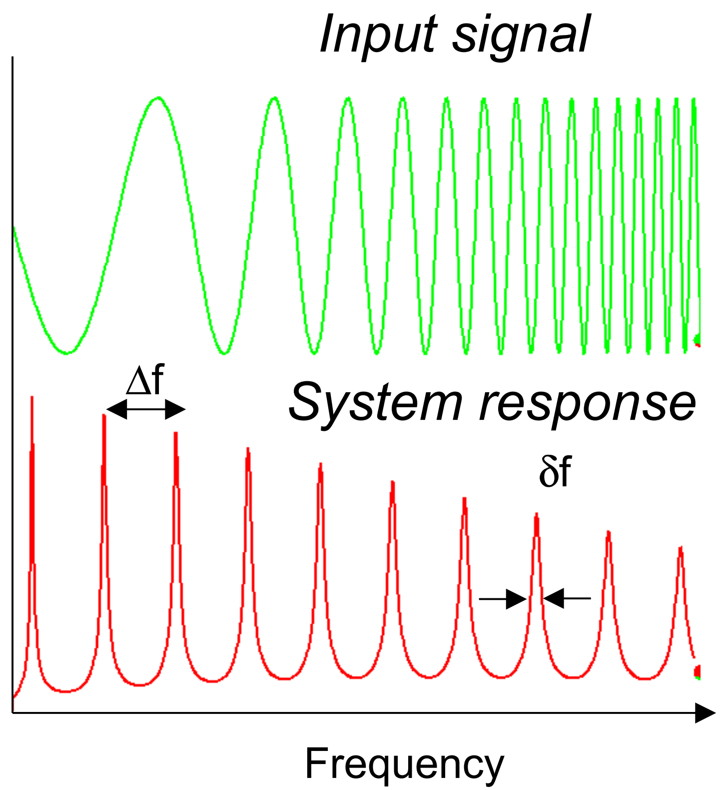
n=1, 2, 3…

λ=wavelength









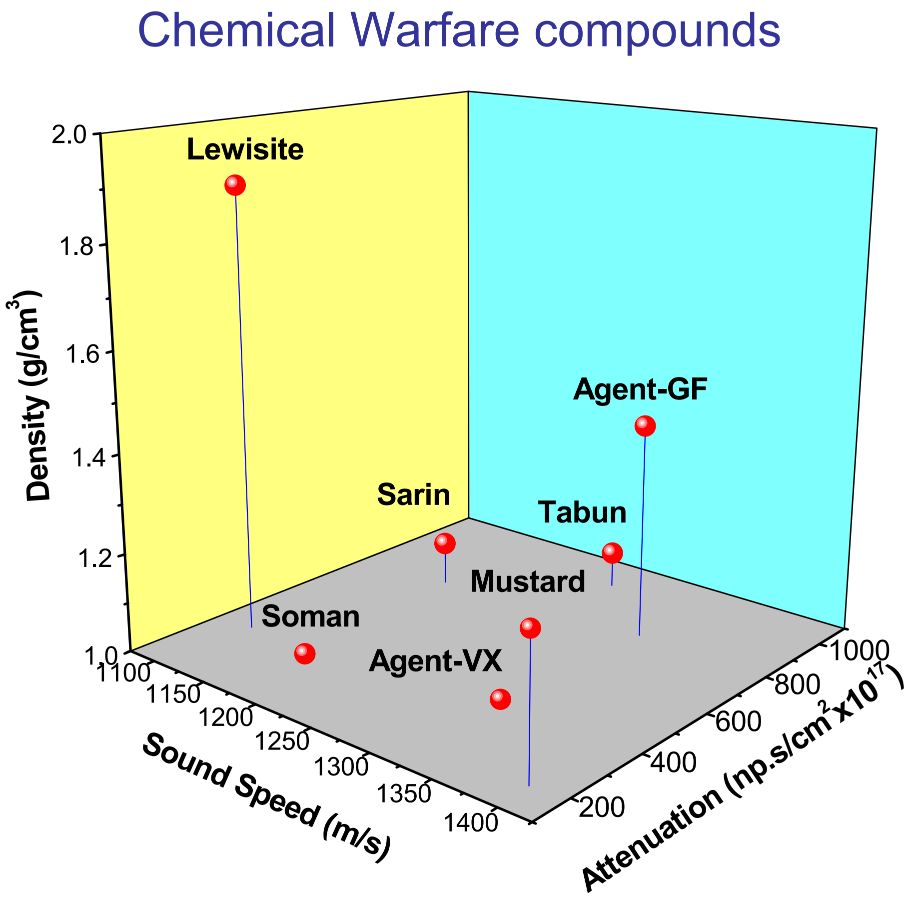
Sound speed = $2d\Delta f$

Sound absorption $\propto$ δ

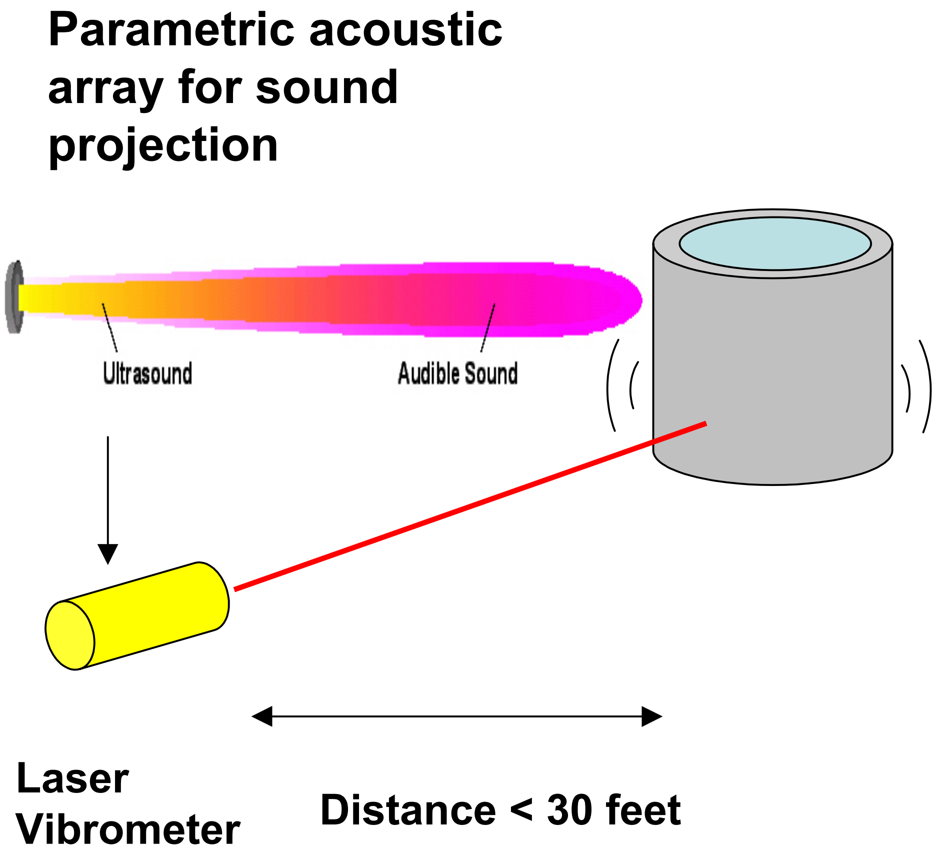
Δf =frequency spacing

Δf =peak width

Swept Frequency Acoustic Interferometry Instrument and CW agent identification

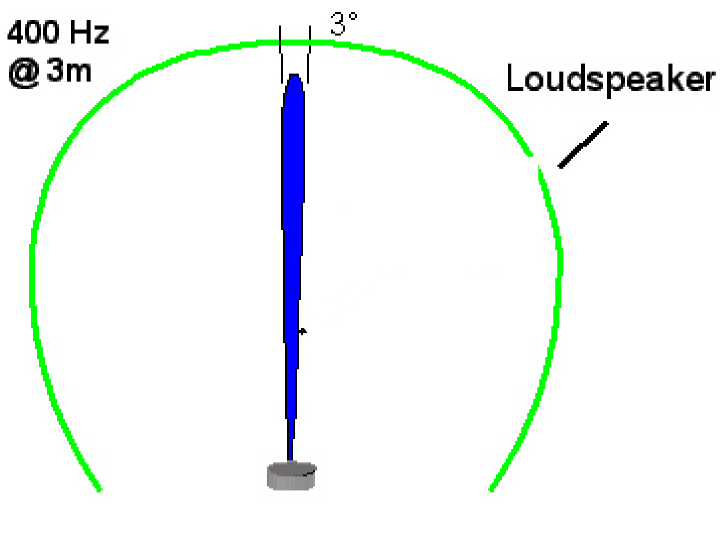


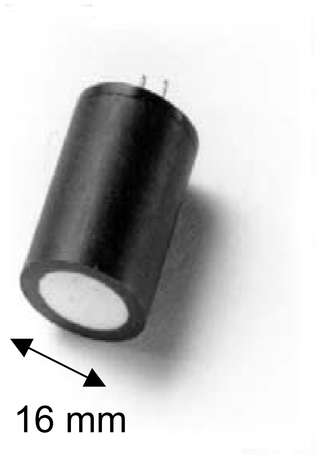
Stand-Off Characterization of Fluids Inside Sealed Containers



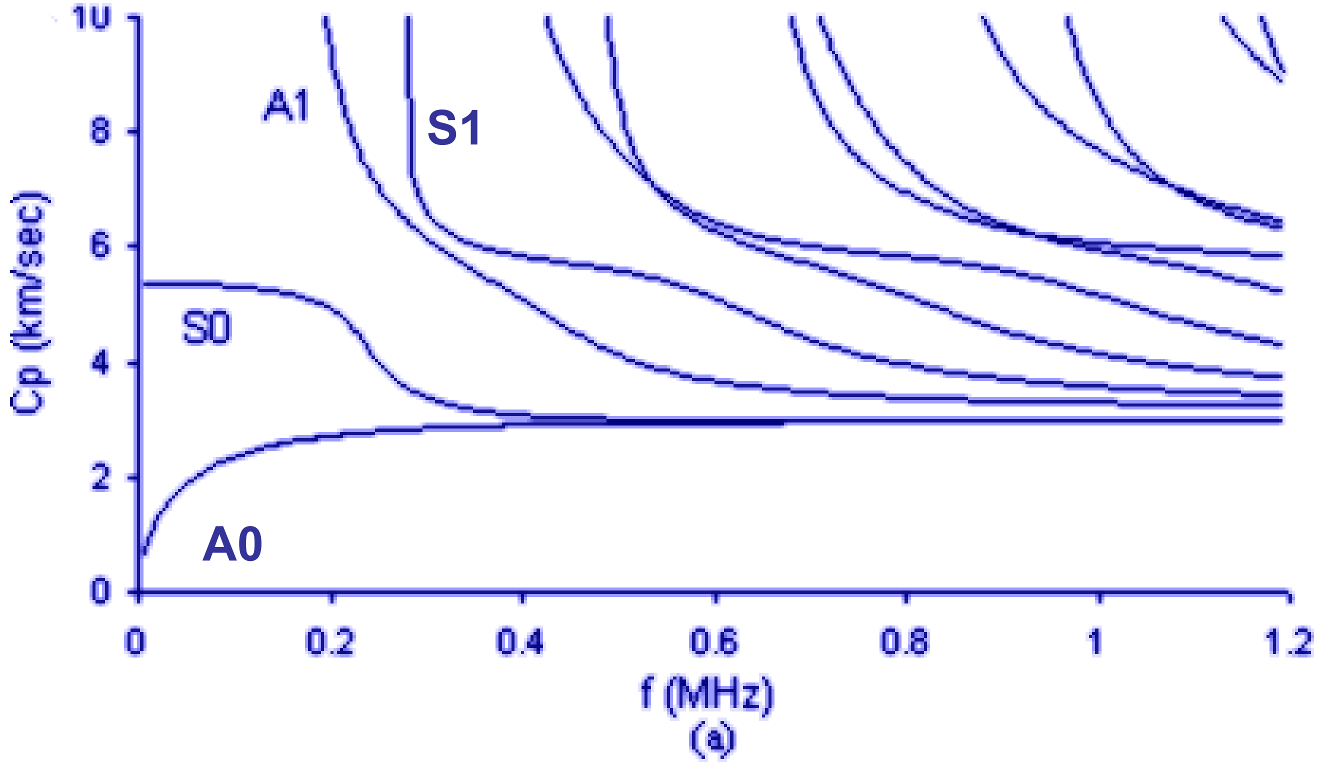
Parametric Acoustic Array: Hyperdirectivity, Wide-bandwidth

$$\text{Beam Spread} \propto \frac{c}{f.D}$$



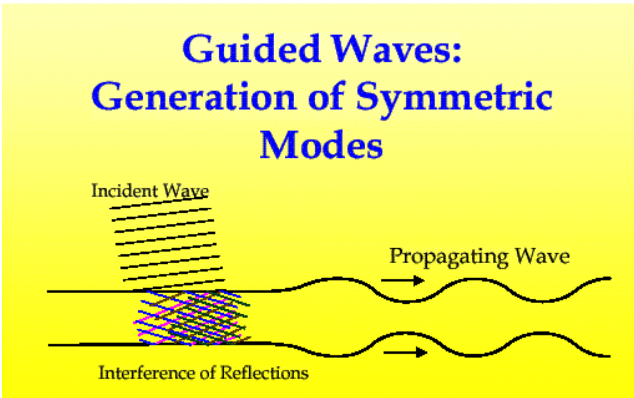


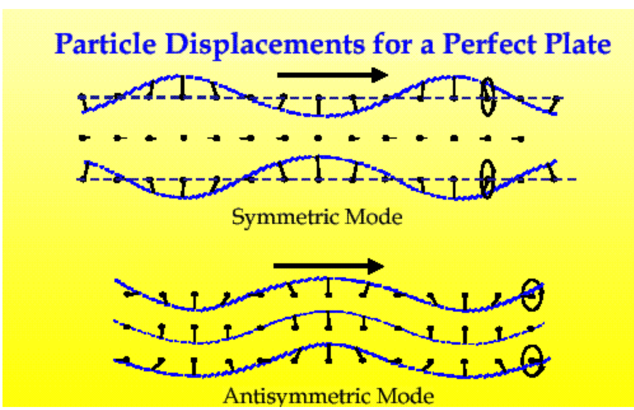
Guided Wave Dispersion

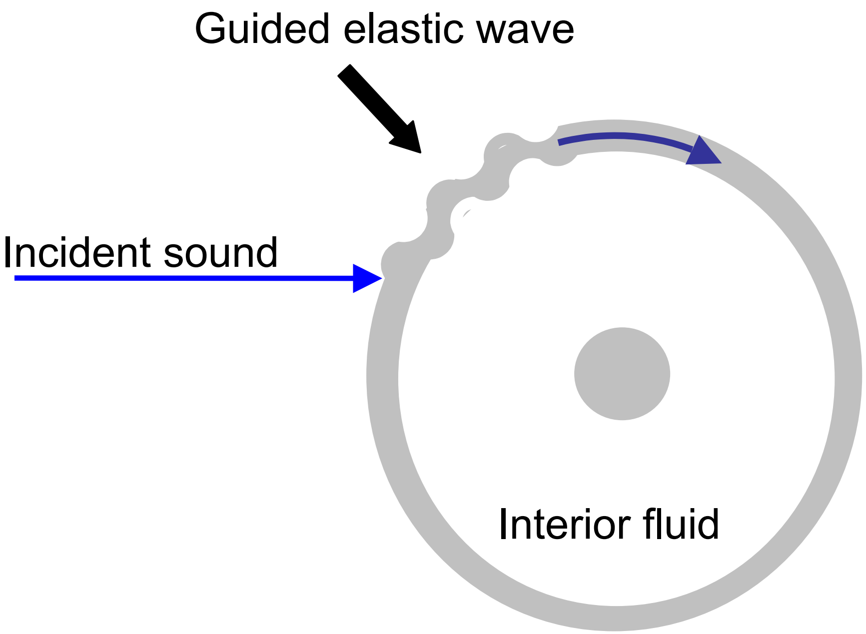


Guided waves are highly sensitive to material characteristics
And changes in material properties including defects

Guided Waves: Generation and Propagation







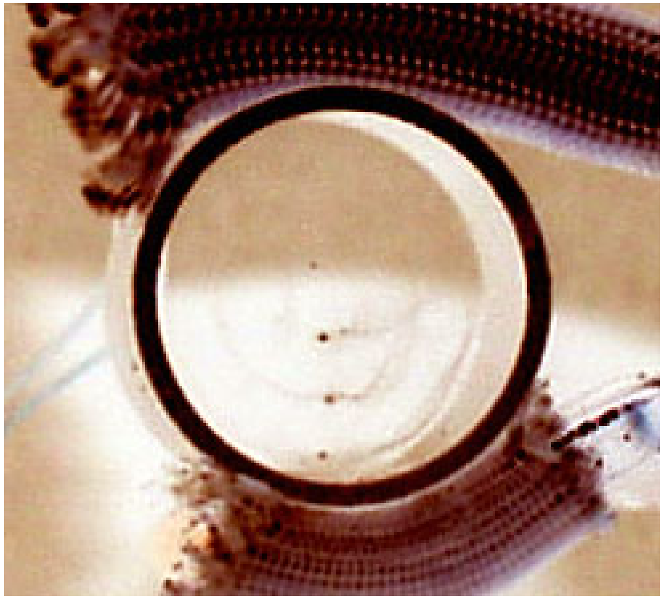
Resonance occurs at $f_{res} = n\ \lambda_{gw}$

Guided wave properties may be used to determine:

- interior fluid density
- interior fluid attenuation
- shell diameter
- shell thickness or material
- interior fluid sound speed composition

Acoustic Levitation and Concentration

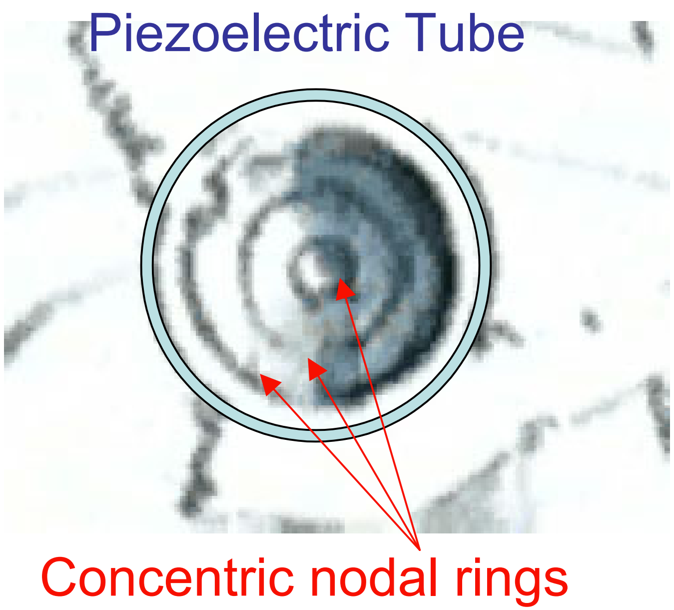
Levitated water drops



Drop diameter ~ 0.9 mm

Drive power ~ 115 mW

Concentration of Aerosol



Concentration factor ~ 100

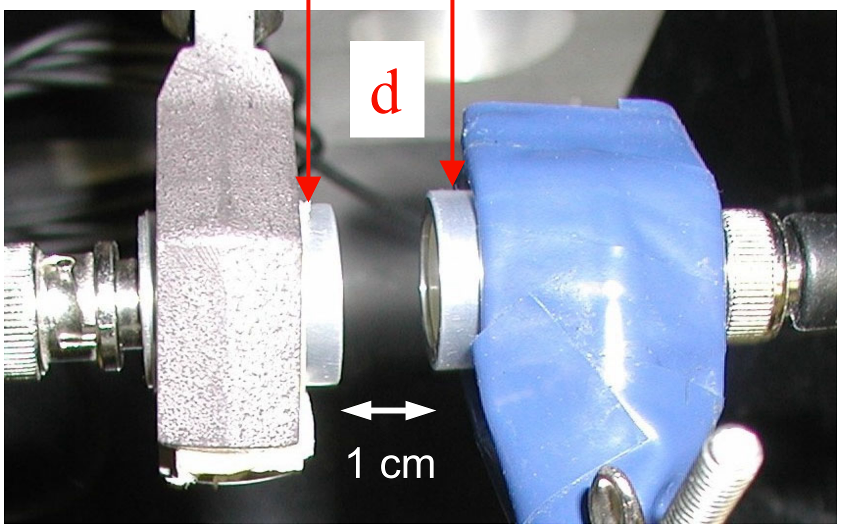
Two orders of magnitude more efficient than conventional methods

Detection of Contamination

Detect contamination added to natural gas in Pipeline.

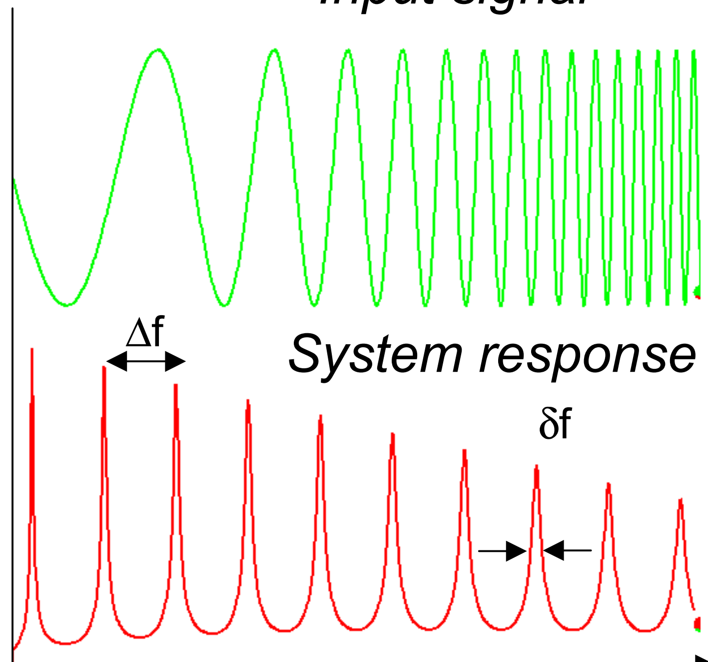
Sound Interference in Transmission Mode

Piezoelectric Transducers



Measurement of sound speed and sound absorption as a function of frequency

Input signal



Frequency

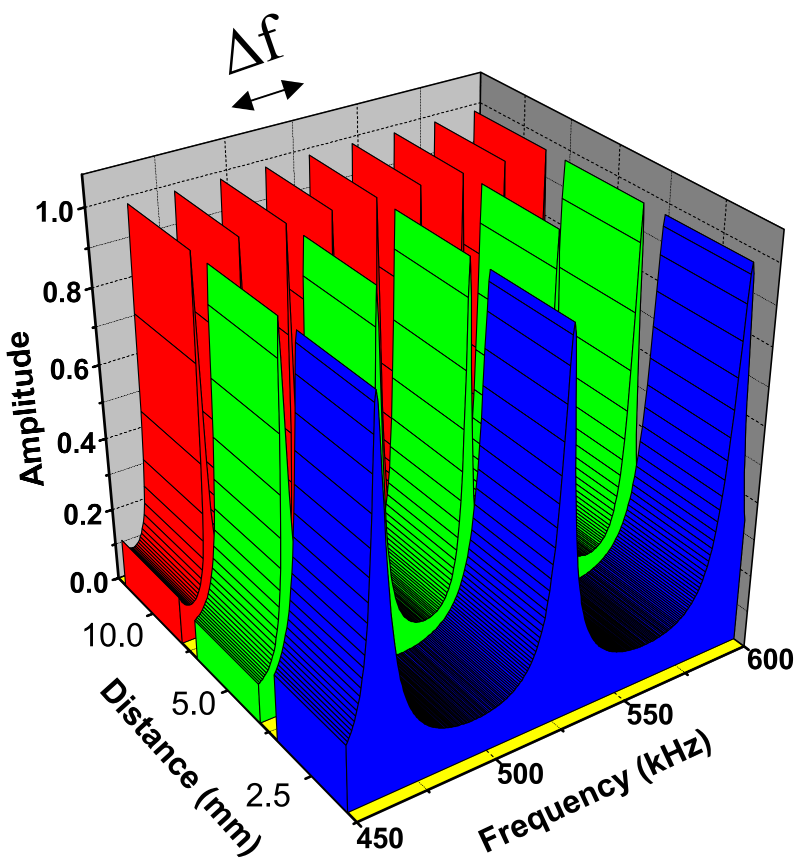
Sound speed = $2d\Delta f$

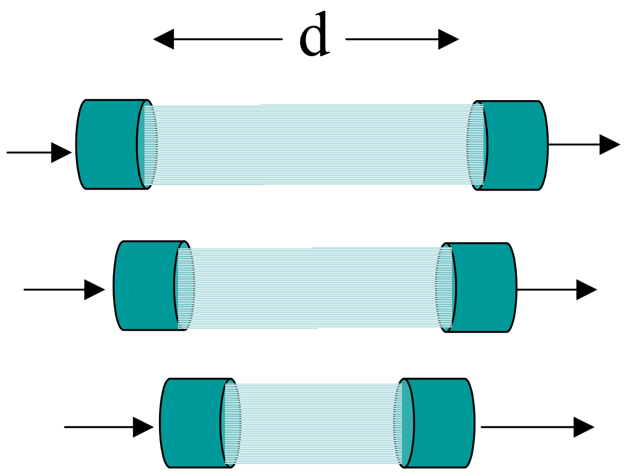
Sound absorption $\propto \delta f$

Δf =frequency spacing

Δf =peak width

Interference Pattern as a Function of Separation





$$c = 2.d.\Delta f$$

The sensitivity of the technique can be easily adjusted by varying the frequency and the distance

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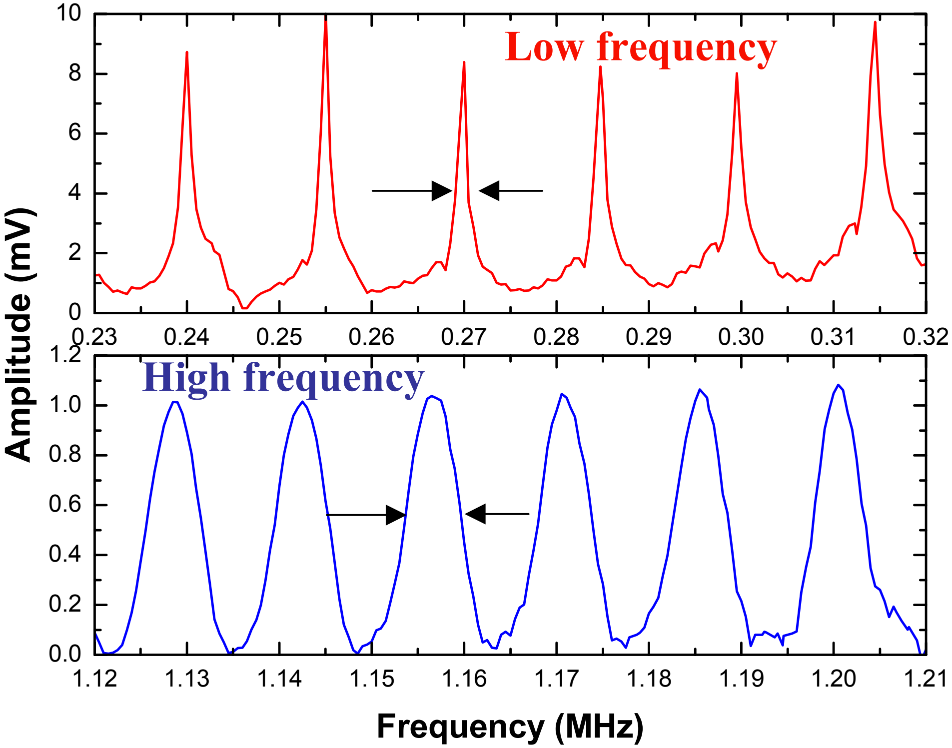
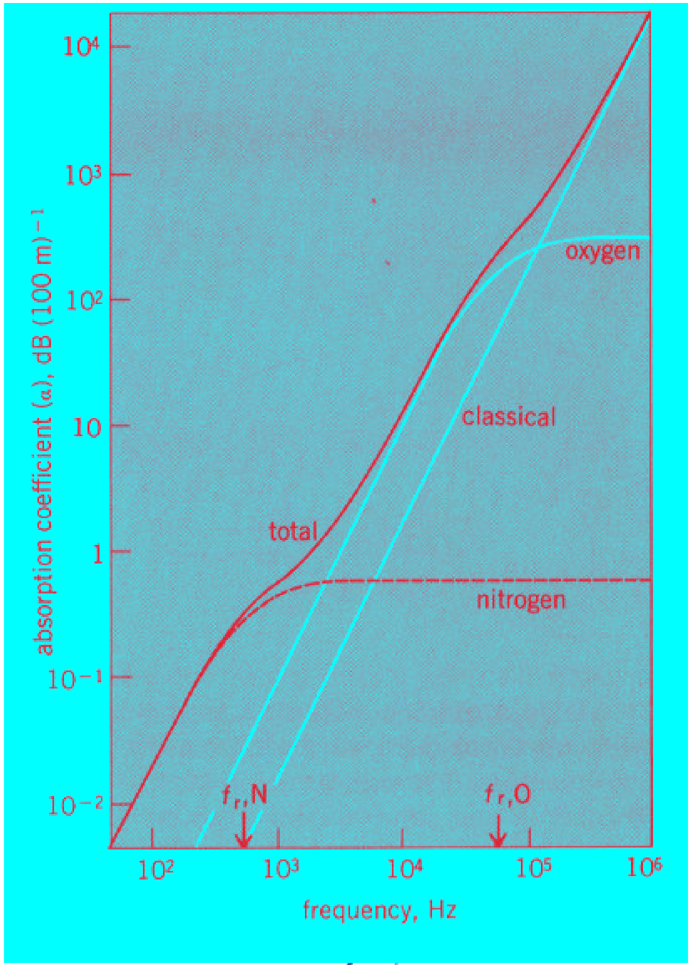
Sound Absorption in Air as a Function of Frequency



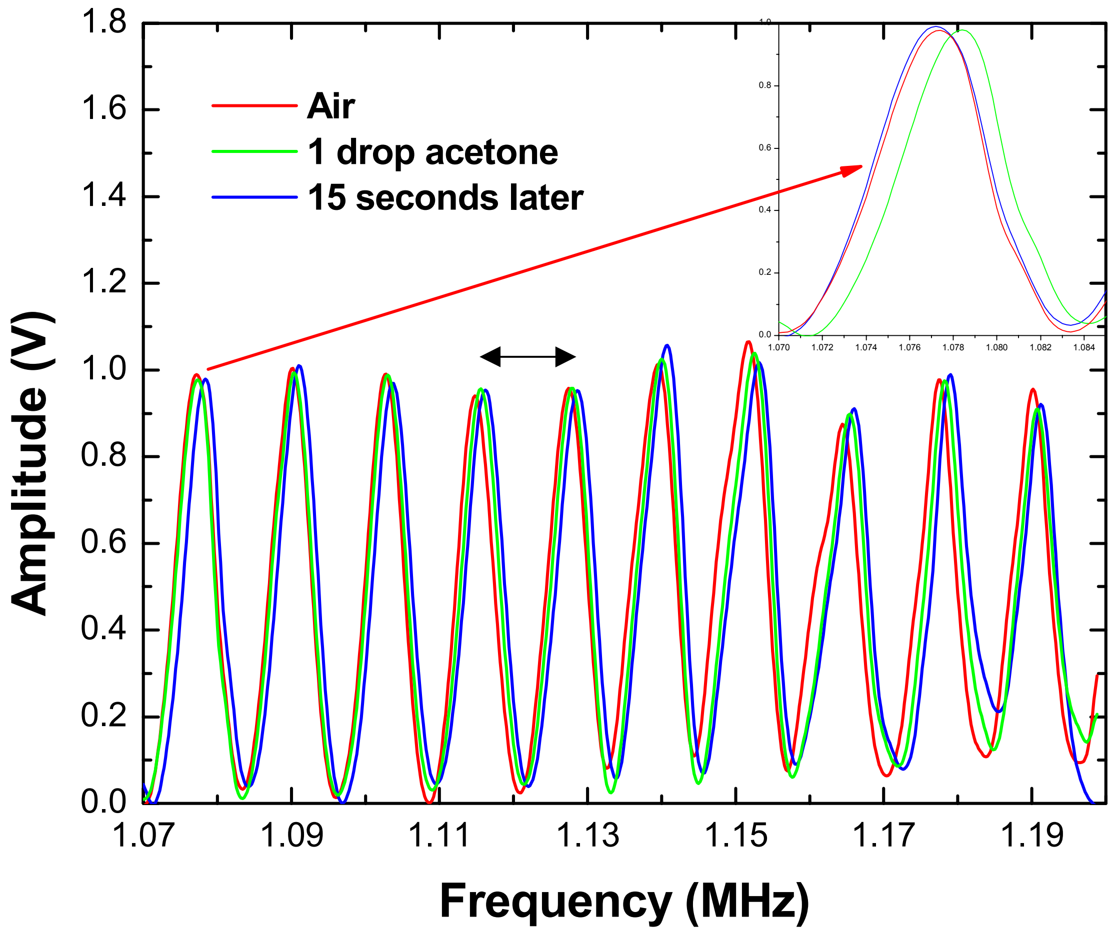


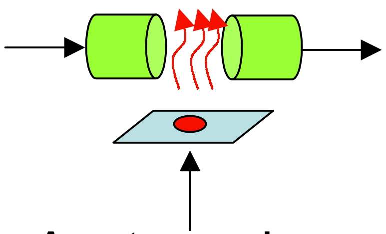
Absorption a $\approx$ 1 x 10^{-10} f^2

2 kHz < f < 100 kHz

50% relative humidity

Effect of Acetone Vapor on Measurement





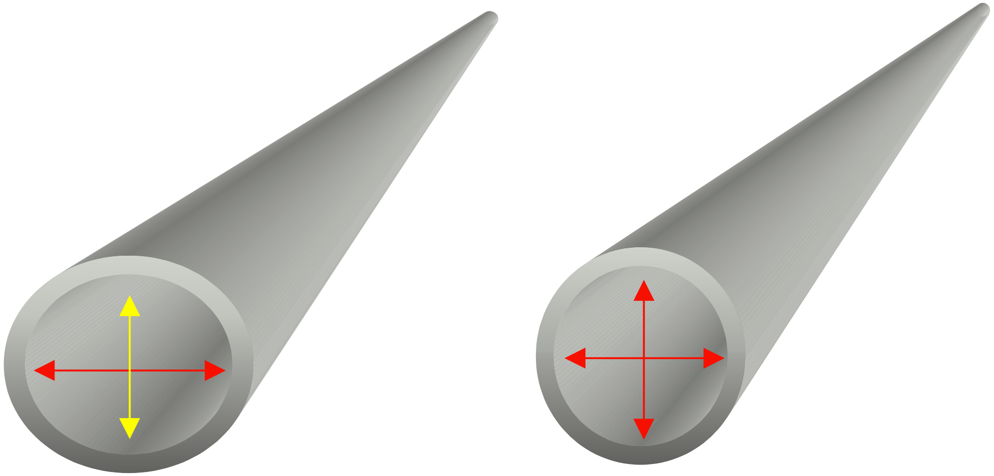
Acetone drop evaporating

$$\boxed{c = 2d\,\Delta f}$$

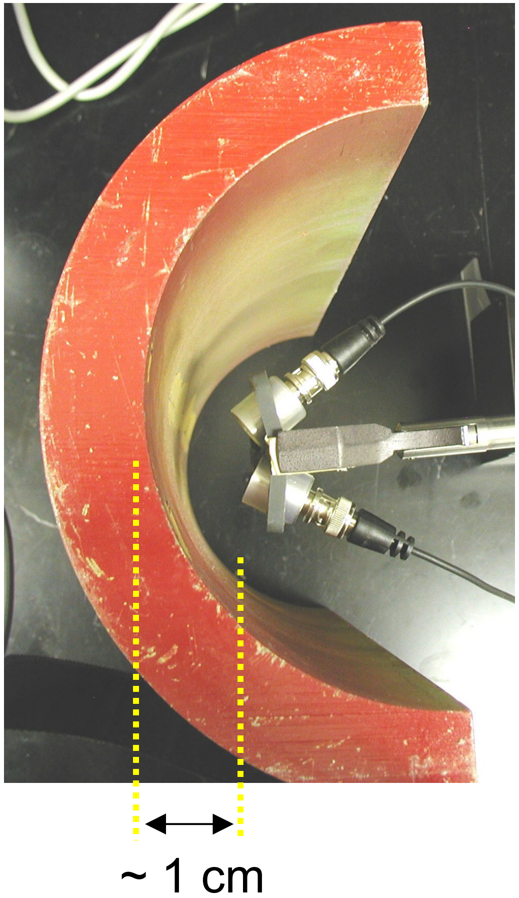
C= sound speed

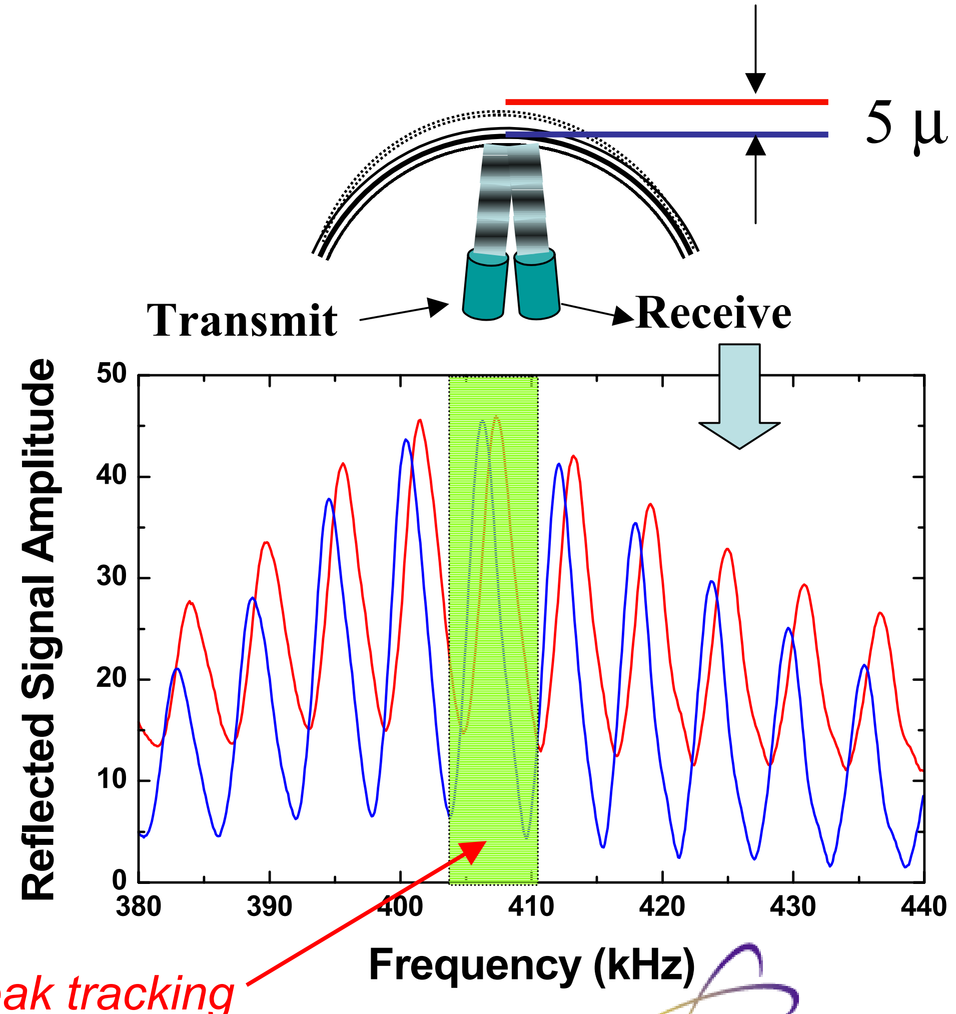
Deformation of Pipeline Cross-section

Determination of the ovality of the pipe



Pipeline Internal Cross-Section Measurement





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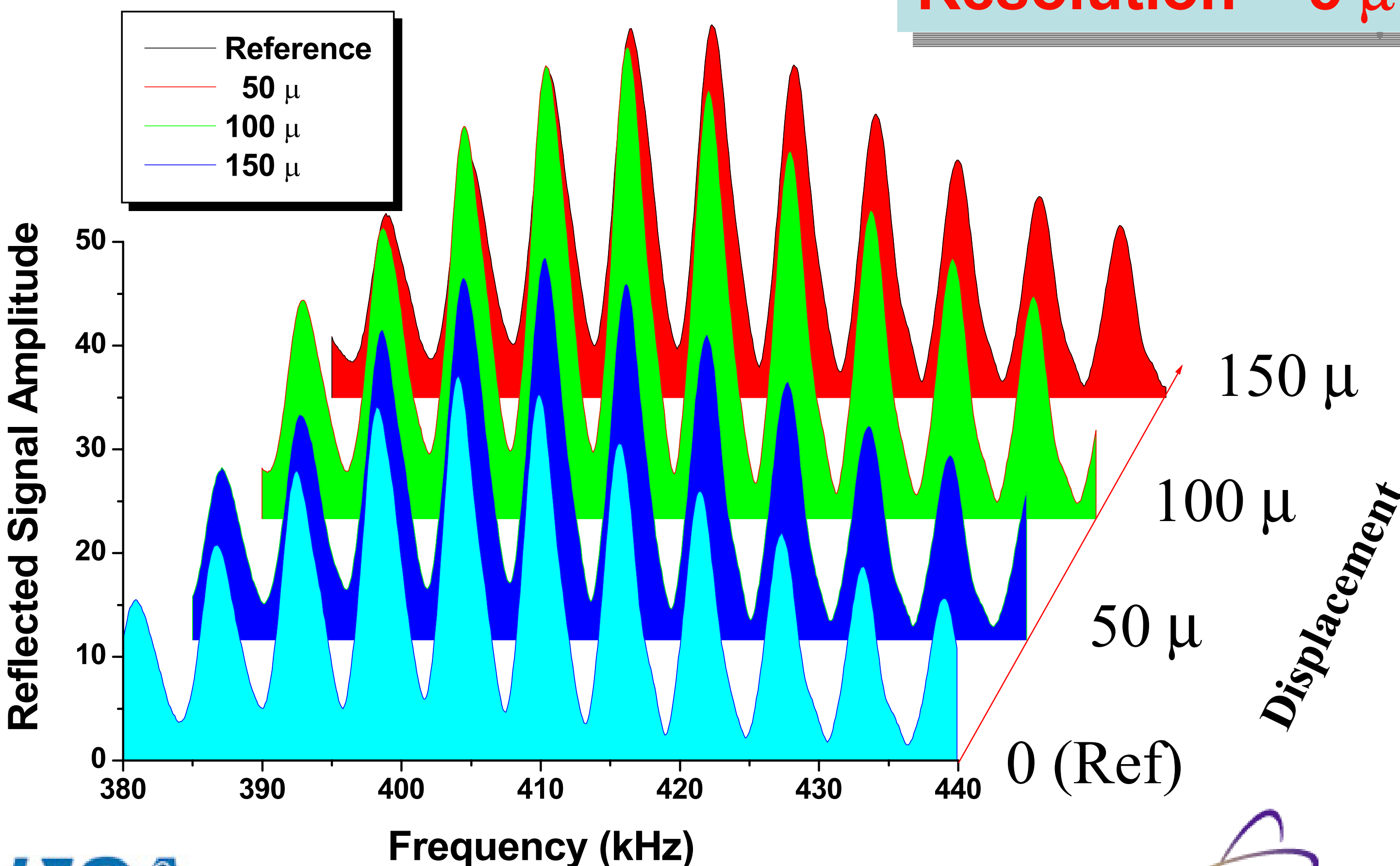
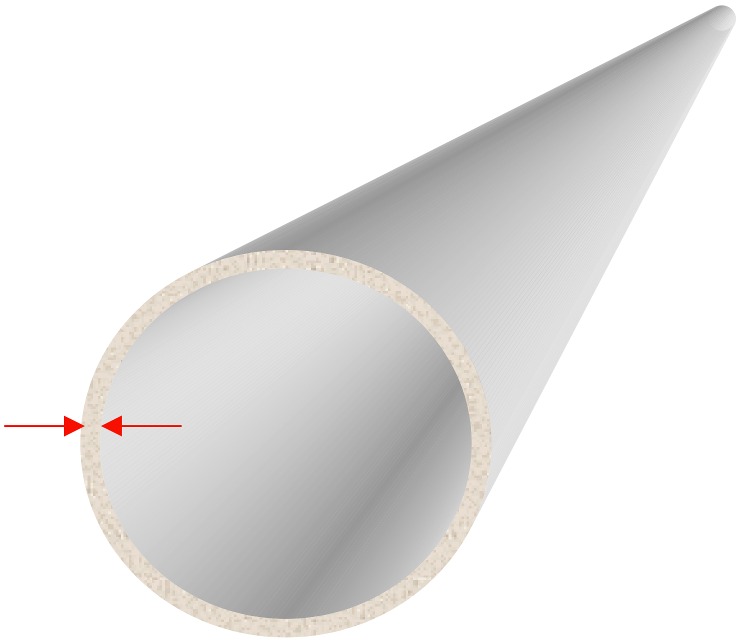
Sensitivity of Cross-Section Measurement

Resolution ~ 5 µ

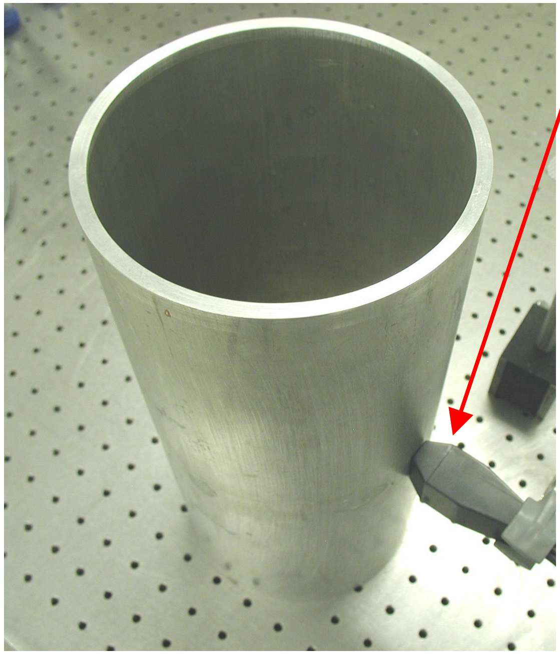


Pipeline Wall Thickness Monitoring

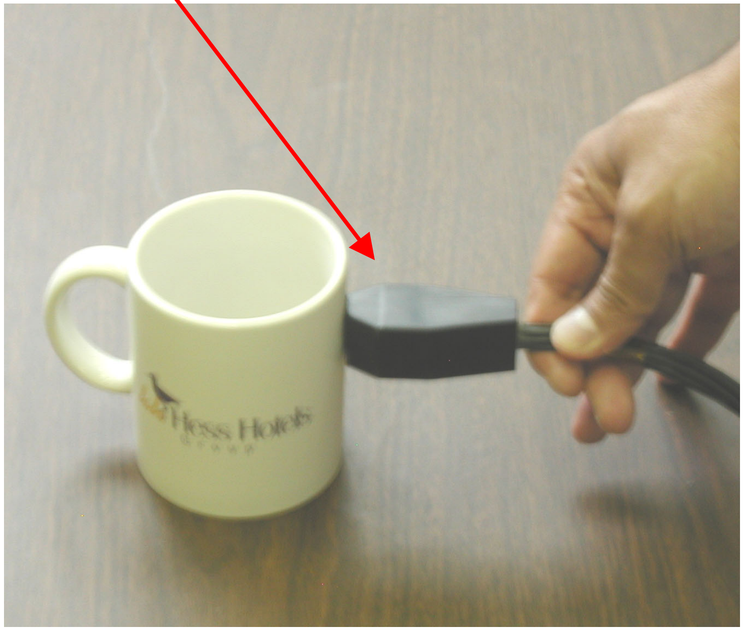


Simultaneous Wall Thickness and Sound Speed Determination

Piezoelectric Sensor Head



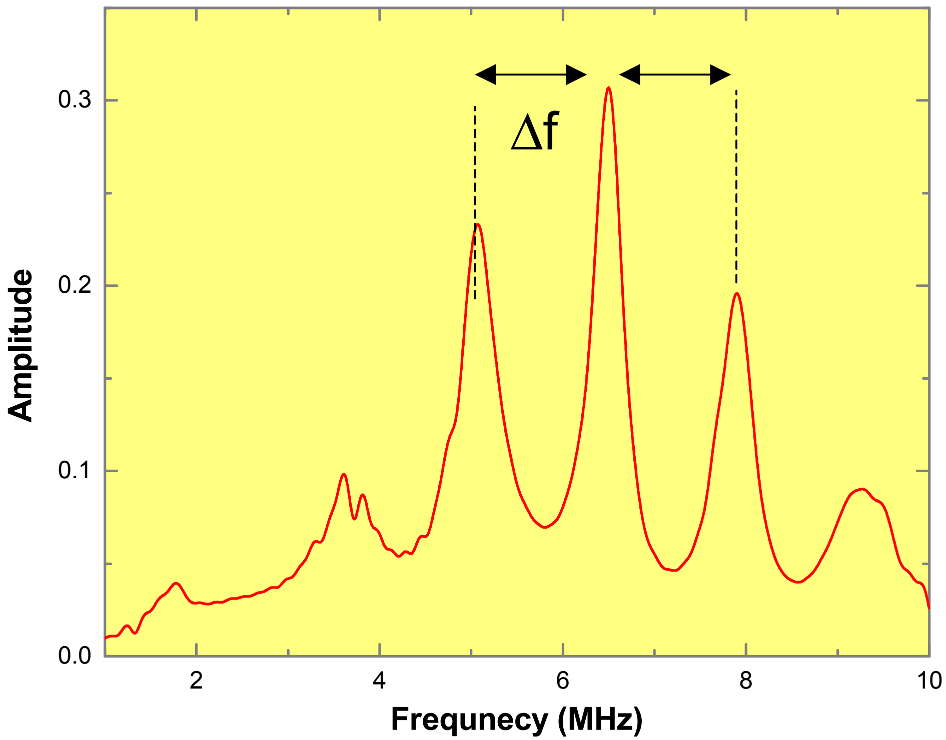
Aluminum Pipe

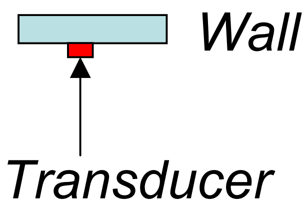


Coffee Mug

Working on noncontact approach

Determination of Wall Thickness using Standing Waves





Time

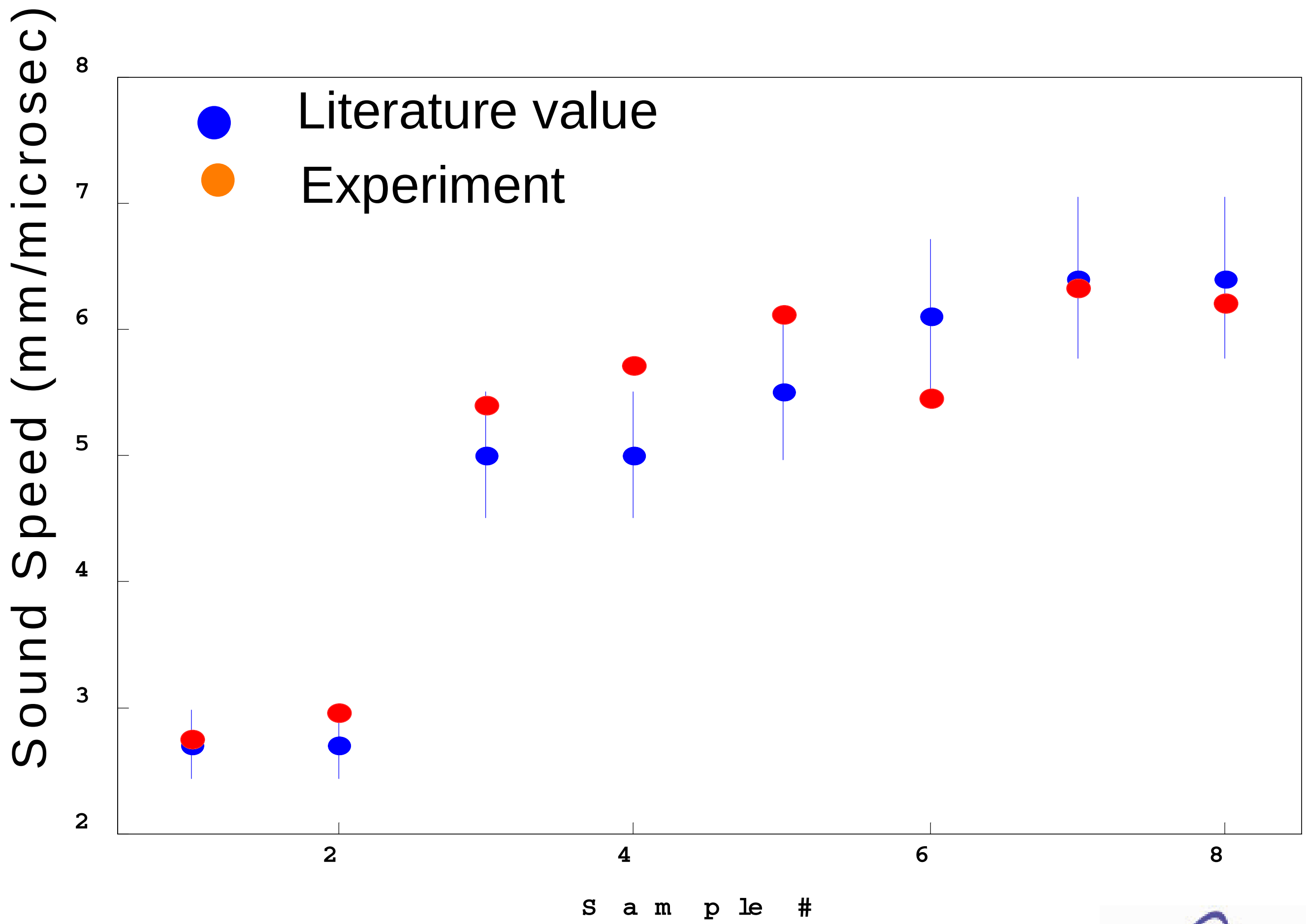
Sound speed = $2d\Delta f$

Sound absorption $\propto$ δ

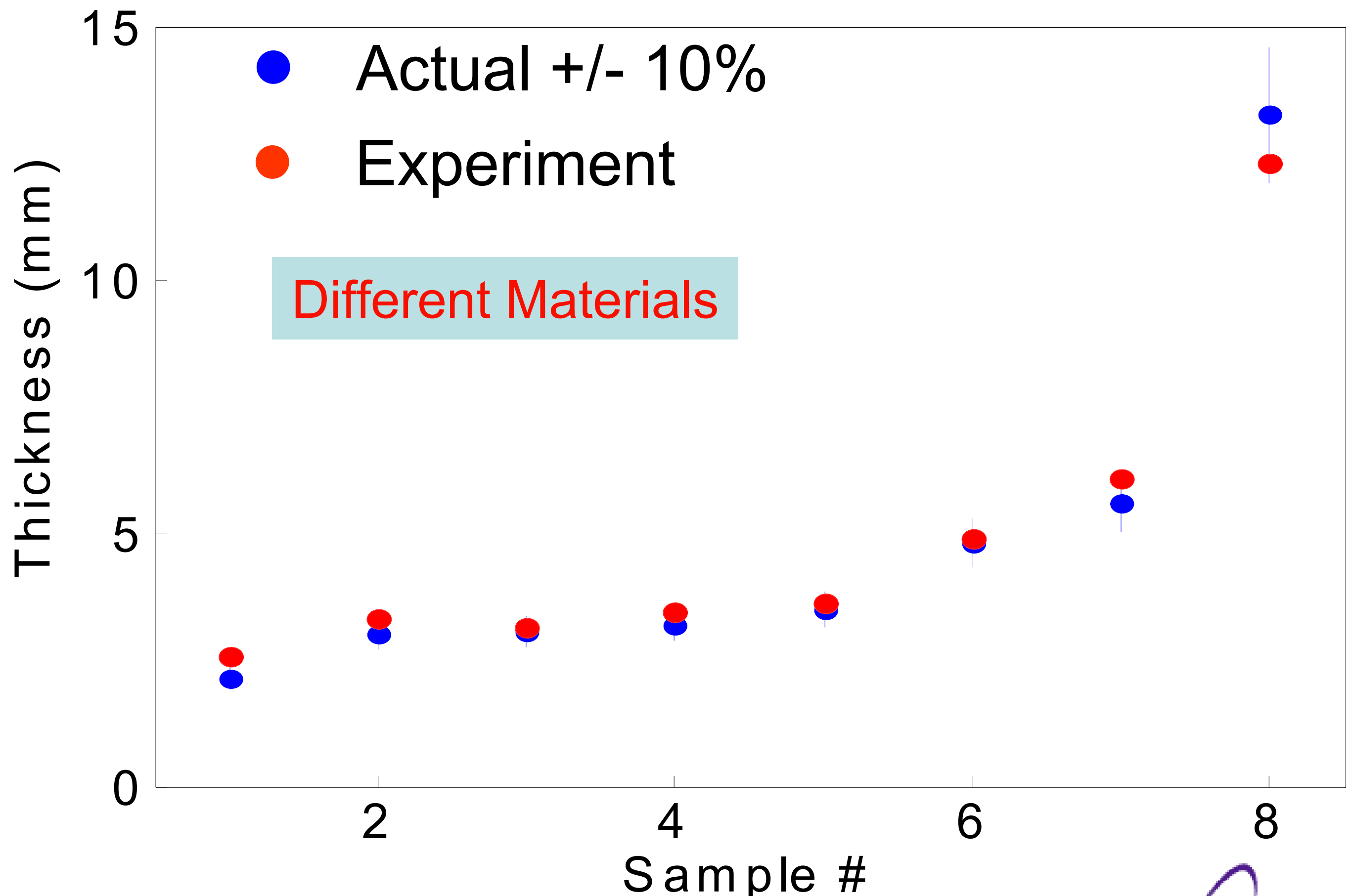
Δf =frequency spacing

Δf =peak width

Sound Speed Results



Wall Thickness Results



Conclusions

Acoustic sensing (frequency-based technique) shows promise in monitoring various aspects of structural integrity of natural gas pipelines.

Wall thickness, wall material properties, pipe cross-section variation, and sensitive method to detect contamination in gas have been demonstrated.